ANTENNA STANDARDS

Frequency (MHz)	Category	Maximum beam width to 3 dB points (included angle in degrees)	Minimum antenna gain (dBi)	Minimum radiation suppression to angle in degrees from centerline of main beam in decibels: 5° to 10°	10° to 15°	15° to 20°	20° to 30°	30° to 100°	100° to 140°	140° to 180°
932.5 to 935	A	14.0	N/A		6	11	14	17	20	24
941.5 to 944	B	20.0	N/A			6	10	13	16	20
952 to 960 [1,4]	A	14.0	N/A		6	11	14	17	20	24
	B	20.0	N/A			6	10	13	15	20
1,850 to 2,500 [2]	A	8.0	N/A	12	18	22	25	29	33	39
	B	8.0	N/A	5	18	20	20	25	28	38
3,700 to 4,200	A	N/A	36	23	29	33	36	42	55	55
	B	N/A	36	20	24	28	32	32	32	32
5,925 to 6,875 [10]	A	N/A	38	25	29	33	36	42	55	55
	B	N/A	38	20	24	28	32	35	36	36
6,525 to 6,875 [11]	A	1.5	N/A	26	29	32	34	38	41	49
	B	2.0	N/A	21	25	29	32	35	39	45
10,550 to 10,680 [5,9]	A	3.4	34	20	24	28	32	35	55	55
	B	3.4	34	20	24	28	32	35	35	39
10,565 to 10,615 [3,12]	N/A	360	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
10,630 to 10,680	N/A	N/A	34	20	24	28	32	35	36	36
10,700 to 11,700 [10]	A	N/A	38	25	29	33	36	42	55	55
	B	N/A	38	20	24	28	32	35	36	36
12,200 to 13,250 [6]	A	1.0	N/A	23	28	35	39	41	42	50
	B	2.0	N/A	20	25	28	30	32	37	47
17,700 to 19,700 [9]	A	N/A	38	25	29	33	36	42	55	55
	B	N/A	38	20	24	28	32	35	36	36
21,200 to 23,600 [6]	A	N/A	38	25	29	33	36	42	55	55
	B	N/A	38	20	24	28	32	35	36	36
31,000 to 31,300 [7,8]	N/A	4.0	38	N/A	N/A	N/A	N/A	N/A	N/A	N/A
38,600 to 40,000	A	N/A	38	25	29	33	36	42	55	55
	B	N/A	38	20	24	28	32	35	36	36

[1] Except for frequencies listed in Sec. 94.65(a)(1), where omnidirectional antennas may be used.
[2] Except for 2,150–2,160 MHz, where the maximum beamwidth is 360 degrees.
[3] Except as provided for in paragraph (h) of this section.
[4] Antennas used at outlying stations as part of a central protection alarm system need conform to only the following 2 standards: (1) The minimum on-beam forward gain must be at least 10 dBi, and (2) the minimum front-to-back ratio must be at least 20 dB.
[5] Except as provided in §94.91.
[6] Except for temporary-fixed operations in the band 13200 MHz – 13250 MHz with output powers less than 250 mW and as provided in §94.90.
[7] The minimum front-to-back ratio shall be 38 dBi.
[8] Mobile, except aeronautical mobile, stations need not comply with these standards.
[9] Except for such antennas between 140 deg. and 180 deg. authorized or pending on January 1, 1989 for which minimum radiation suppression to angle (in degrees) from centerline of main beam is 36 decibels.
[10] These antenna standards apply to all point-to-point stations authorized after June 1, 1997. Existing licensees and pending applicants on that date are grandfathered and need not comply with these standards.
[11] These antenna standards apply to all point-to-point stations authorized on or before June 1, 1997.
[12] These antenna standards apply only to Digital Termination User Stations licensed, in operation, or applied for prior to July 15, 1993.

Microwave Communication

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Table 11-2. Typical worst-case commercial parabolic antenna gain (dB relative to isotropic radiator).

Diameter m (ft) / Frequency (GHz)	0.6(2)	1.2(4)	1.8(6)	2.4(8)	3.0(10)	3.7(12)	4.6(15)
1.9	—	25.0	28.5	31.0	32.9	34.5	36.4
2.1	—	25.8	29.3	31.9	33.8	35.4	37.3
2.2	—	26.3	29.3	32.2	34.2	35.7	37.6
2.4	—	27.2	30.9	33.3	35.2	36.9	—
2.5	—	—	31.0	33.5	—	—	—
2.6	—	27.9	31.1	33.6	35.4	37.4	—
3.7	—	—	—	36.8	38.8	40.4	42.3
3.9	—	—	—	36.8	38.8	40.4	42.3
4.0	—	31.4	34.9	37.3	39.0	41.0	42.7
4.7	—	33.0	36.4	38.9	40.8	42.4	44.3
5.9	—	—	—	—	42.9	44.5	—
6.2	—	35.0	38.5	41.3	43.1	44.8	46.4
6.8	—	36.0	39.4	42.0	43.8	45.4	46.9
7.4	—	36.5	40.0	42.5	44.5	46.0	47.7
8.0	—	37.1	40.7	43.3	45.2	46.7	48.6
8.1	—	37.2	40.8	43.3	45.2	46.7	48.6
8.4	—	—	41.0	43.5	45.4	47.0	48.8
10.6	34.1	39.6	43.1	—	—	—	—
11.2	34.5	40.5	44.0	46.4	47.8	49.8	51.3
12.5	35.4	40.7	44.8	47.3	48.5	50.6	51.6
12.7	35.5	40.8	45.1	47.6	48.8	50.9	51.9
13.0	35.6	41.0	45.1	47.6	48.8	50.9	—
14.9	36.5	42.5	46.1	48.6	50.5	—	—
18.7	38.5	44.7	—	—	—	—	—

Table 11-3. Typical copper corrugated elliptical waveguide loss.

Frequency (GHz)	Waveguide Type	Loss	
		dB/100 m	dB/100 ft
1.9	EW20	2.0	0.60
2.1	EW20	1.7	0.52
2.2	EW20	1.6	0.49
2.4	EW20	1.5	0.45
2.5	EW20	1.4	0.44
2.6	EW20	1.4	0.43
3.7	EW37	3.1	0.94
3.9	EW37	2.9	0.87
4.0	EW37	2.8	0.85
4.7	EW44	4.0	1.2

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Telecommunications Industry Association
2001 Pennsylvania Avenue, NW
Washington, DC 20006-1813
USA

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2.5.4 Threshold degradation considerations in analog (FM-FDM, FM-Video) systems

C/I ratios for threshold degradation are often misleading since they require the use of assumed values for receive signal level and fade margin. When the fade margin required for the desired path reliability (outage) is limited by thermal noise, a more suitable approach is the stipulation of the maximum allowable interfering signal level. Threshold degradation interference results primarily in the degradation of the victim's practical threshold which defines its mute (outage) point. In FM-FDM systems, this threshold is usually defined as that faded RF carrier level that produces a flat S/N of 30 dB in the worst voice channel. For FM-Video systems, this threshold is defined as that RF carrier level that produces a 37 dB peak-to-peak luminance signal to RMS noise ratio with EIA weighting. In an FM system, the post detection S/I or S/N (in a message channel or across the video passband) is perhaps 10-20 dB larger than the input C/I or C/N in the RF/IF bandwidth. As an example, the S/I (or S/N) in the top (2,540 kHz) 3.1 kHz VF channel in a 600 channel link deviated ±140 kHz RMS (±200 kHz peak) with a 10 MHz IF bandwidth is

$$
\begin{aligned}
\frac{S}{I}\left(\frac{S}{N}\right) &= \frac{C}{I}\left(\frac{C}{N}\right) + 10\log\left(\frac{\Delta f}{f}\right)^2 + 10\log\left(\frac{B_{IF}}{2B_{VF}}\right) + \textit{Emphasis} \\
&= \frac{C}{I}\left(\frac{C}{N}\right) + 10\log\left(\frac{0.2}{2.54}\right)^2 + 10\log\left(\frac{10{,}000}{2\times 3.1}\right) + 4.0 \qquad (2.5.4\text{-}1) \\
&= \frac{C}{I}\left(\frac{C}{N}\right) + 14.0, \quad \textit{dB (signal to flat noise ratio)}
\end{aligned}
$$

Insert 2

For FM-Video systems (f = 4.2 MHz, Δf = ±4 MHz peak), and other non-multiplexed, non-sinusoidal broadband signals like radar (*see* Annex C),

$$
\begin{aligned}
\frac{S}{I}\left(\frac{S}{N}\right) &= \frac{C}{I}\left(\frac{C}{N}\right) + 10\log\left(3\left[\frac{\Delta f}{f}\right]^2\right) + 10\log\left(\frac{B_{IF}}{2f}\right) + (\textit{Emphasis} + \textit{Weighting}) \\
&\quad + \frac{P-P}{RMS} \qquad (2.5.4\text{-}2) \\
&= \frac{C}{I}\left(\frac{C}{N}\right) + 10\log\left(3\left[\frac{4}{4.2}\right]^2\right) + 10\log\left(\frac{25}{8.4}\right) + 9.2 + 6.1 \\
&= \frac{C}{I}\left(\frac{C}{N}\right) + 24, \quad \textit{dB p-p luminance signal to RMS weighted noise ratio}
\end{aligned}
$$

where

B_{vf}	=	VF channel baseband, kHz
B_{IF}	=	IF bandwidth, MHz or kHz
Δf	=	peak per-channel deviation, kHz
	=	peak video deviation., MHz
f	=	VF channel frequency, kHz
	=	video bandwidth, MHz
I	=	in-band interference level, dBm
N	=	in-band thermal noise level, dBm
	=	$-114 + 10\log(B_{IF}) + NF$
NF	=	noise figure, dB

Intert 3

Similar computations derive the S/I(S/N) for links with other parameters (bandwidth, deviations, *etc.*). The Annexes A (FM-FDM) and C (FM-Video) curves derive C/I criteria to meet the S/I objectives for the co- and adjacent-channel coordination of victim and interfering FM systems with both similar and dissimilar baseband and FM modulation characteristics.

The following equation may be used to establish the maximum interfering signal level for analog receiver threshold degradation in FM-FDM and FM-Video links. Short, non-fading, and other hops with high receive signal levels will accept higher interference levels and continue to meet performance (unfaded noise, fade margin, and outage) objectives.

$$I_{max} = R_t + F_e + S_e(f_e) - 10 \qquad (2.5.4\text{-}3)$$

where:

I_{max}	=	maximum interfering signal level, dBm
R_t	=	receiver threshold, dBm
F_e	=	the difference between the operating fade margin and that required to meet the outage objective, dB
S_e	=	effective selectivity of the victim receiver to the interfering signal, dB
(f_e)	=	interfering signal frequency at which S_e is defined

Effective selectivity (in dB) is supplied by the equipment manufacturer and is mainly a function of the IF filter bandwidth(s). In particular, threshold extension IF filtering selectivity in some FM-FDM receivers can have a substantial positive effect on semi-adjacent and adjacent channel interference. However, threshold extension (narrower) IF filters could increase sensitivity to co-channel interference by lowering the threshold of the victim receiver.

2.5.5 Interference criteria and Considerations related to victim digital systems

The primary interference consideration for digital victim systems is threshold degradation because performance is not significantly affected when the desired signal level is more than about 10 dB above its outage (10^{-3} BER) threshold. The interference effects are primarily related to the total power of the analog or digital interference falling into the digital receiver's noise ("baud-rate") bandwidth rather than to its spectral shape or modulation type. Most digital systems employ data stream regeneration at each hop to prevent an accumulation of interference and spectrum distortion (dispersion) effects. For this reason, it is possible to consider the effects of interference separately for each digital hop regardless of whether it is part of a long-haul or short-haul system.

Previous versions of this Bulletin addressed coordination only in the Private Operational-Fixed Microwave Service bands. As of December 1993, FCC *ET Docket 92-9* re-channelized all of the fixed microwave bands and opened them to both private and common carrier users. Prior to this action, slightly different interference calculations were used for coordination in the common carrier and private microwave bands. In order to accommodate these changes, this version of the Bulletin provides an approach which mediates between the previous methods. This harmonized approach and its relation to the previous methods is described in this section. Since available information on existing systems is not sufficient to allow any of these methods to be applied to all the situations that can arise in practice, a set of default calculations is provided in Annex B.

More accurate assessments of interference effects can be made when appropriate information is obtained from the equipment manufacturers. A discussion of the possible form of this information and its application is also given in Annex B. Until the form and application of this information is agreed to by the user community and the information is available, the method described below should be used where possible; otherwise one of the default procedures in Annex B can be used.

Similar computations derive the S/I(S/N) for links with other parameters (bandwidth, deviations, *etc.*). The Annexes A (FM-FDM) and C (FM-Video) curves derive C/I criteria to meet the S/I objectives for the co- and adjacent-channel coordination of victim and interfering FM systems with both similar and dissimilar baseband and FM modulation characteristics.

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where:

- I_{max} = maximum interfering signal level, dBm
- R_t = receiver threshold, dBm
- F_e = the difference between the operating fade margin and that required to meet the outage objective, dB
- S_e = effective selectivity of the victim receiver to the interfering signal, dB
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Effective selectivity (in dB) is supplied by the equipment manufacturer and is mainly a function of the IF filter bandwidth(s). In particular, threshold extension IF filtering selectivity in some FM-FDM receivers can have a substantial positive effect on semi-adjacent and adjacent channel interference. However, threshold extension (narrower) IF filters could increase sensitivity to co-channel interference by lowering the threshold of the victim receiver.

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The effect of interference on a victim digital receiver is determined from the threshold-to-interference (T/I) ratio which provides the means of specifying the sensitivity of a victim receiver to an interferer. The static (non-fading) threshold (T) of a digital receiver is defined, for purpose of interference (T/I) calculations, as that manually faded (with attenuators) receive carrier level that produces a Bit Error Rate (BER) of 10^{-6}. T/I is defined as that ratio of desired (10^{-6} BER) to undesired (interfering) signal levels that degrades this threshold by 1 dB. The 10^{-3} dynamic (outage) threshold is similarly degraded 1 dB by this level of interference.

The advantages of T/I are that the differences in thresholds, due to bit rate, modulation technique (transmission efficiency), coding gain and noise figure, are all taken into account, that the absolute level of allowable interference can be easily determined by subtracting the T/I ratio from the 10^{-6} static threshold of a particular digital receiver, and that this measurement can be verified in service without disrupting traffic. However, in any actual situation, the value of T/I depends primarily on the victim receiver's total (RF/IF/baseband) selectivity (bandwidth), the interfering signal's RF spectrum bandwidth, and the separation between their center frequencies.

The measurement of T/I for a digital radio is accomplished by fading the receiver to the point where a 10^{-6} BER is present on the link. The signal level is then increased 1 dB and interference injected until a BER of 10^{-6} is again achieved on the link. The ratio of the initial (10^{-6} BER) power level of the desired received signal to the interference power, as measured, is the T/I ratio. Note that this value may vary for different interferers, especially if the interfering signal is offset from and/or has a spectrum wider than the victim receiver's bandwidth.

In principle, one would need to know the T/I as a function of frequency separation for all possible interferers into a digital receiver. Examples of such a T/I curve, which shall be designated as $TI_{vi}(f_d)$ to denote its dependence on the specific equipments and the frequency separation, is shown in Figure B-3. While it would be desirable to require a manufacturer to provide specific T/I curves for all possible interferers and separations into each type of victim receiver, such requirement is clearly impractical.

A specific T/I curve, determined from measurement, should always be used for coordination with a specific interferer if it is available. If one is not available, the procedure described in Annex B should be used to develop the specific T/I curve.

The acceptable value of interference in a coordination process, I_{coord}, dBm, is then given by

$$I_{coord} = T_s - TI_{vi}(f_d) - MEA \qquad (2.5.5\text{-}1)$$

with

$$MEA = \text{Greater of} \begin{cases} 5 \\ 10 \log (BW_V / BW_I) \end{cases} \qquad (2.5.5\text{-}2)$$

where

T_s	=	static threshold power for 10^{-6} BER, dBm
TI_{vi}	=	specific T/I curve, dB
f_d	=	separation of interference and receiver center frequencies
MEA	=	multiple exposure allowance, dB
BW_V	=	RF channel bandwidth of victim receiver, MHz
BW_I	=	RF channel bandwidth of interferer, MHz

MEA, the multiple exposure allowance, is intended to account for the high usage density in the former common carrier bands and for the multiple near-adjacent channel exposures in the mixed-bandwidth frequency plans in these and other bands that were adopted in December 1993 by *FCC ET Docket 92-9*. There is general agreement that a 5 dB MEA is to be used. However, further study as to the upper level of MEA is needed since MEA levels even greater than 5 dB may be appropriate in congested areas due to a higher probability of multiple exposures.

The preceding results can also be expressed in terms of the ratio of the nominal carrier power to the interference power, which is usually referred to as the C/I. The C/I, dB, due to a single specific interferer separated in frequency by f_d, would be given by

$$\begin{aligned} C/I &= C - T_s + TI_{sp} \\ &= TFM_s + TI_{sp} \end{aligned} \tag{2.5.5-3}$$

where TFM_s is the static Thermal Fade Margin to 10^{-6} BER in dB.

It is worth noting for reference that in the common carrier bands prior to 1994, frequency coordination was based on meeting C/I objectives, which in the present terminology would be written as

$$(C/I)_{obj} = TFM_s + TI_{sp} + MEA \tag{2.5.5-4}$$

The default static thermal fade margins in dB at 10^{-6} BER upon which these high C/I objectives were based were the following: 35 (2 GHz), 40 (6 and 18 GHz), 45 (11 and 13 GHz).

2.5.6 Digital microwave fade margins

The composite fade margin (CFM) of a digital microwave link, described in Section 4.2.3, is a more complex parameter than the thermal fade margin for analog radio links. Unlike analog links affected by interference during non-fading periods, interference and spectral distortion effects are a routine and acceptable part of the digital radio composite fade margin calculation used in outage (path reliability) calculations.

CFM is one of the parameters necessary to compute the expected outage on a given hop. When the C/I objective is not met, interference degrades the CFM which increases link outage. However, interference levels even 1-10 dB or more above the 1 dB threshold degradation objective are usually acceptable on shorter or other non-fading digital paths since performance is not adversely affected.

Section 4.2 of this Bulletin, "Performance as a Coordination Criterion in Victim Microwave Links", provides one possible design procedure that could be used to determine these higher interference levels into digital microwave receivers on short and other low fade activity hops and into very short-haul routes.

threshold degradation impacting upon outage time is rarely the dominant interference criterion into a victim FM-FDM or FM-Video analog radio link.

Digital microwave link performance defines its path reliability (annual outage) and quality (BER[1], percent error-free seconds) characteristics during available periods. A digital microwave link is considered in a failed or traffic disconnect state, and thus unavailable for performance prediction or verification, after and then including a 10-second duration outage event. Such long-term outage events are unacceptable to most users, the single exception being predictable rain outage allocated to "local grade" metropolitan area and other high-frequency (above 10 GHz) links. A discussion of rain outage and other factors affecting high-frequency microwave link availability is in Section 4.4 of this Bulletin.

Interference usually impacts upon only the path reliability (annual short-term outage), not the quality nor the availability, of a properly designed digital microwave radio link. The North American standard for two-way end-to-end trunk "availability" (encompassing, in this context, both short-term and long-term outage events) over either a short-haul (to 400 km / 250 mi) or long-haul (to 6,400 km / 4,000 mi) route is 99.98% (0.02% downtime). One half is allocated to long-term unavailability events (rain outage, equipment failure, power fades), the other half (0.01%) to two-way short-term multipath fade outage events thus deriving the 0.005% or 1,600 sec/yr one-way outage objective for these longer routes.

The outage objective for star systems and other very short-haul (<400 km / 250 mi) systems with fewer than about 10 tandem hops is often relaxed to 99.999% per hop.

Assuming that only half of the 6,400 km / 4,000 mi long-haul, but all of the 400 km / 250 mi short-haul, microwave paths are fading, the one-way short-term outage objectives may be computed as 0.5 sec/km/yr (0.8 sec/mi/yr) in all or part of a long-haul system and 4 sec/km/yr (6.4 sec/mi/yr) in all or part of a short-haul system.

An outage in a digital microwave link is internationally defined as a 10^{-3} BER severely-errored second (SES) event that coincides closely to an out-of-frame (OOF) or loss of synchronization condition in downstream multiplexers. This corresponds to the 30 dB S/N ratio worst message channel mute (outage) point in most FM-FDM analog microwave radio links. Thus, digital microwave radios are characterized by two thresholds: the aforementioned 10^{-6} BER operating point to which flat and interference static fade margins are measured during commissioning and in-service (manually, with attenuators), and the 10^{-3} BER outage point (in a hands-off dynamic fade environment) used for CFM and path outage calculations and measurements.

flat weighted

4.2.2 Digital and analog system performance (quality and outage) overview

Section 2.0 of this Bulletin addressed the question "How much interference can the victim receiver tolerate before performance is unacceptably degraded?" Although per-exposure interference criteria were provided in Section 2.5 for long-haul and short-haul analog and digital microwave routes, FCC *Rules and Regulations* intent on efficient spectrum utilization allow users to mutually agree on lesser criteria, for example into shorter routes into links with low fade activity, into links scheduled for decommissioning or upgrade, and into older, noisier microwave systems.

Interference, which degrades the quality (analog link noise, digital link BER) and path reliability (more annual outage) imperceptibly to heavily in microwave systems, should not impact upon the user's stated performance objectives if proper criteria tailored to the victim link are assigned.

[1]

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Assuming that only half of the 6,400 km / 4,000 mi long-haul, but all of the 400 km / 250 mi short-haul, microwave paths are fading, the one-way short-term outage objectives may be computed as 0.5 sec/km/yr (0.8 sec/mi/yr) in all or part of a long-haul system and 4 sec/km/yr (6.4 sec/mi/yr) in all or part of a short-haul system.

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Interference, which degrades the quality (analog link noise, digital link BER) and path reliability (more annual outage) imperceptibly to heavily in microwave systems, should not impact upon the user's stated performance objectives if proper criteria tailored to the victim link are assigned.

[1] Bit Error Rate

A second question then often asked — "What performance objective(s) should be assigned to my microwave links or system?" — greatly influences the allowable per-exposure interference levels. A relaxed short-haul (400 km, 10-hop) system 99.995% one-way reliability objective, equating to 160 sec/yr/hop outage (99.9995%/hop), will accept higher interference levels than a similar 99.995% objective distributed over a typical long-haul (2,500 km, 80-hop) system (20 sec/yr/hop outage, 99.99993%/hop reliability). This is also seen in Section 2.5 — 25 and 5 pWp0 allowable per-exposure interference levels into short- and long-haul analog microwave routes respectively.

It is also reflected in the 1 dB threshold degradation objective for short- and long-haul analog and digital receivers alike. One dB of threshold degradation (loss of fade margin) will increase 160 and 20 sec/yr/hop outage to 200 and 25 sec/yr/hop in non-diversity short- and long-haul links respectively (253 and 32 sec/yr/hop in space diversity links). But if a non-diversity victim path was short or non-fading with less than 2 sec/yr/hop outage, even 3 dB of threshold degradation would only increase it's computed outage to an inconsequential 4 sec/yr.

In partial answer to "What performance objective should be assigned ... ?", the follow table compares published performance (one-way outage) objectives for several telecommunications organizations. The objectives shown are for a typical 40 km (25 mi) analog or digital microwave path.

ITU-R (CCIR)

Parameter	Bellcore Short-haul	CCIR (ITU) High-grade	Long-haul
System length, km (mi)	400 (250)	2,500 (1,500)	6,400 (4,000) **
End-to-end system reliability, %	99.995	99.986*	99.995
End-to-end outage, sec/yr	1,600	4,200*	1,600
Per-hop outage, sec/yr	160	70*	20
Per-hop outage, sec/km/yr (sec/mi/yr)	4 (6.4)	1.7 (2.8)*	0.5 (0.8)
Per-hop outage, sec/any month	52*	24	7*
Per-hop annual path reliability, %	99.9995***	99.9998*	99.99993

ATT

* Not a stated performance objective, but scaled using a 10°C (50°F) average annual temperature.

** Long-haul performance objectives assume only 50% path fade activity (3,200 km, 2,000 mi).

*** Very short-haul (<400 km / 250 mi) outage objectives are often relaxed to 99.999% per hop.

Table 4-1 — Annual Outage Objectives for a Typical 40 km (25 mi) Microwave Link

This table shows that system length has the most influence on per-hop performance objectives. The per-hop performance objectives for a long interstate pipeline or common carrier microwave system are much more demanding, and thus require higher fade margins, more effective diversity schemes and lower interference levels than, for instance, an area-wide star-configured system of an equal number but with many fewer tandemly-connected hops, even though the end-to-end digital trunk or message channel performance objective may be similar. In the absence of a known performance objective, 99.999% annual path reliability is the per-hop default objective for frequency coordination purposes.

Section 2.5/Annex A provides the allowable per-exposure baseband interference (noise) levels into FM-FDM links making up short- and long-haul analog microwave systems. Annex A of this Bulletin contains the C/I ratios for the more commonly encountered interference situations meeting these quality objectives. For conditions not covered by these typical curves, Annex A provides the computation procedures.

It is important to note that the Section 2.5/Annex A noise objectives are for only short- and long-haul routes. For shorter systems (<400 km / 250 mi), the short-haul C/I objectives may be reduced as follows:

$$\frac{C}{I}\,(<400\ km) = \frac{C}{I}_{curve} - 10\log\left(\frac{2010}{D_{km}}\right) \quad [metric]$$

$$\frac{C}{I}\,(<250\ mi) = \frac{C}{I}_{curve} - 10\log\left(\frac{1250}{D_{mi}}\right) \quad [English] \qquad (4.2\text{-}1)$$

The above is consistent with the relaxation of outage objectives for very short digital systems.

4.2.3 Multipath fading outage calculations

The outage time due to multipath fading in a non-diversity link can be calculated from: [2]

$$T = \frac{r\,T_O\,10^{-\left(\frac{CFM}{10}\right)}}{I_o} \qquad (4.2\text{-}2)$$

where:

T	=	annual outage time, seconds
r	=	fade occurrence factor
T_o	=	(t/50) (8 x 10^6) = length of the fade season, seconds
t	=	average annual temperature in °F (°C x 9/5 + 32)
CFM	=	Composite Fade Margin (digital links) or Fade Margin (analog links), dB
I_o	=	Space Diversity Improvement Factor: = 1 for non-diversity, >1 for diversity

One must be cautioned that the composite fade margin for a digital radio link is a more complex parameter than the thermal fade margin for analog radio links in that interference and spectral distortion effects are an additional and acceptable part of the digital radio fade margin calculation.

The composite fade margin for a digital microwave link is comprised of three or four parts:

The Thermal (or flat) Fade Margin (TFM)

[2] Arvids Vigants, "Space Diversity Engineering", *Bell System Technical Journal*, Jan. 1975, pp. 103-142., from Equation 2 (English units). NOTE: The equations are not applicable for paths under 22.5 km (14 miles). Private communications, Arvids Vigants (Bell Telephone Laboratories) to Donald Draper Campbell (Federal Communications Commission), June 1978.

The Dispersive Fade Margin (DFM)
The External Interference Fade Margin (EIFM or IFM)
The Adjacent Channel Interference Fade Margin (AIFM), in multiline systems

These fade margins are power-added to constitute the Composite Fade Margin (CFM) used for path reliability (outage) computations. The calculation is given as follows:[3]

$$CFM = -10 \log \left[10^{-\frac{TFM}{10}} + 10^{-\frac{DFM}{10}} + 10^{-\frac{EIFM}{10}} + 10^{-\frac{AIFM}{10}} \right] \tag{4.2-3}$$

These composite fade margin components are defined as follows: 8

TFM: Thermal Fade Margin (dB). TFM is the algebraic difference between the nominal received carrier level and the 10^{-3} BER outage threshold for flat (non-dispersive) fades. Since interference affects unfaded baseband noise, TFM (usually to 30 dB S/N) is the only fade margin in analog links.

DFM: Dispersive Fade Margin (dB), also to 10^{-3} BER. DFM, manufacturer-defined, is determined by the type of modulation, the effectiveness of the equalization employed in the receiver, and the multipath signal's delay time (standardized in manufactures' data sheets at 6.3 nsec). DFM characterizes the digital radio's robustness to dispersive (spectrum-distorting) fades. Increased antenna discrimination to reduce the amplitude of longer-delayed multipath signals that would otherwise unacceptably degrade the link's DFM may be required (>50 dB link DFM is a suitable criterion).

EIFM: External Interference Fade Margin (dB). Receiver threshold degradation due to interference from a total of 3 (MBA factor) external systems (usually 1 dB, but depends on CFM objective). In the usual absence of parallel radio adjacent-channel interference (AIFM), EIFM is simply IFM.

AIFM: Adjacent-channel Interference Fade Margin (dB). Receiver threshold degradation due to interference from adjacent channel transmitters on the same path due to transmitters in one's own system. This is normally a negligible parameter except in frequency diversity and 1 x N multiline systems.

NOTE: The 10^{-3} BER threshold is the recognized outage threshold for all digital microwave receivers in a dynamic fade environment. However, factory and field TFM, EIFM, AIFM, and other non-fading static tests with attenuators are to the 10^{-6} BER in-service (non-disruptive) point. This is valid since a 1 dB degradation in the 10^{-6} BER point (due to higher receiver noise figure or interference) also occurs at the 10^{-3} BER outage point.

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3 Bell Communications Research TR-TSY-000752, "Microwave Digital Radio Systems Criteria", Issue 1, October 1989.

The fade occurrence factor, r, is calculated using the basic outage equation for atmospheric multipath fading: [4]

$$r = c\left(\frac{f}{4}\right)\left(\frac{D}{1.6}\right)^3 10^{-5}$$

or

$$= x\left(\frac{16}{w}\right)^{1.3}\left(\frac{f}{4}\right)\left(\frac{D}{1.6}\right)^3 10^{-5} \quad [metric]$$

(4.2-4)

$$= c\left(\frac{f}{4}\right) D^3 \times 10^{-5}$$

or

$$= x\left(\frac{50}{w}\right)^{1.3}\left(\frac{f}{4}\right) D^3\ 10^{-5} \qquad [English]$$

where:

c	=	Climate-Terrain Factor (see map, Figure 4-2)[5]
x	=	Climate Factor (see map, Figure 4-3)
w	=	terrain roughness [6]
		$6 \le w \le 42$ m — average 15 m or
		$20 \le w \le 140$ ft — average 50 ft
f	=	frequency, GHz
D	=	path length, km [miles]

4 Derived from Equations 3, 4 and 5 — Arvids Vigants, "Space Diversity Engineering", *Bell System Technical Journal*, Jan. 1975, pp. 103-142.

5 Climate-Terrain Map and Climate Map were digitized by Donald Draper Campbell, FCC, January 1994, from maps developed by Bell Laboratory (AT&T). See, Letter, J.P. Robertson, AT&T, to Donald Campbell, FCC, dated 17 February 1983.

6 With respect to calculating the roughness factor from a path profile, w, a minimum of 15 equally spaced points should be used. Private communications, Arvids Vigants (Bell Telephone Laboratories) to Donald Draper Campbell (Federal Communications Commission), June 1978. This alternate calculation is tailored to the path profile, and therefore is more accurate than using the "c" factor. See Annex B in Vigants' paper (above) for this alternate procedure.

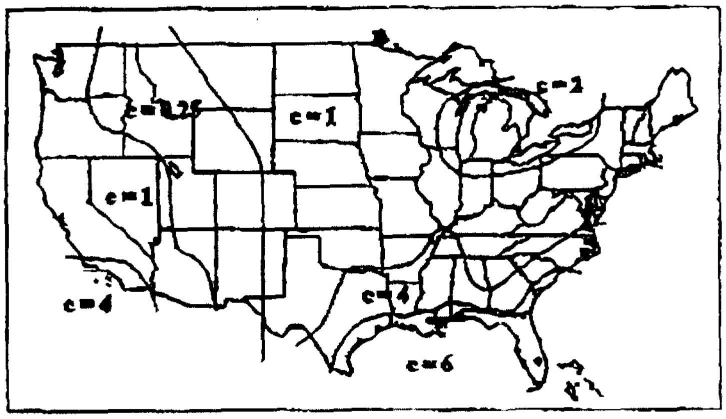

Figure 4-2 — Values of Climate-Terrain Factor, "c"

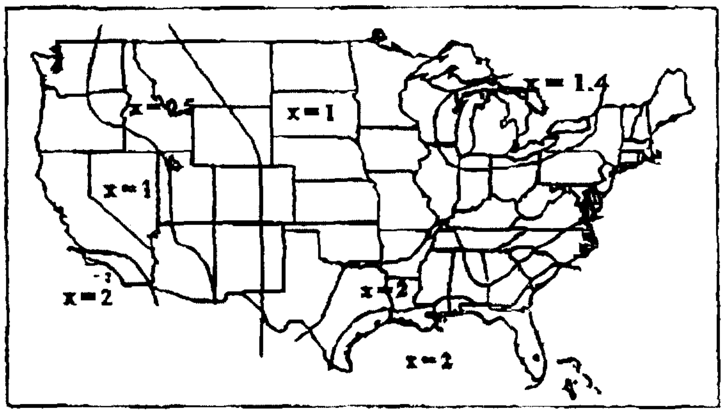

Figure 4-3 — Values of Climate Factor, "x"

Hawaii	Alaska
c=4 / x=2	c=0.25 / x=0.5: coastal and mountainous areas c=1 / x=1: flat permafrost tundra areas in west and north Alaska

$$I_o = 1.2\times10^{-3}\, s^2 \left(\frac{f}{D}\right) 10^{\frac{CFM}{10}}, \quad s \le 15 \text{ meters} \quad [metric]$$

$$= 7\times10^{-5}\, s^2 \left(\frac{f}{D}\right) 10^{\frac{CFM}{10}}, \quad s \le 50 \text{ feet} \quad [English] \qquad (4.2\text{-}5)$$

where:

fade margins on both antennas are about equal, and
s = vertical antenna separation in meters (feet), center to center.

The Space Diversity Improvement Factor (I_o) may underestimate diversity improvements for small antenna spacings and over estimate diversity improvement for large antenna spacings on "flat land" microwave links.[7]

For the purposes of this Bulletin, average climate [x = 1], temperature [10°C (50°F)], and terrain roughness [15 m (50 ft)], conditions may usually be assumed. This simplifies the outage time equation to:

$$T = \frac{5\, f\, D^3\, 10^{-\frac{CFM}{10}}}{I_o} \quad [metric]$$

$$= \frac{20\, f\, D^3\, 10^{-\frac{CFM}{10}}}{I_o} \quad [English] \qquad (4.2\text{-}6)$$

It is seen from the above equations that non-diversity multipath outage increases directly as a function of the path length cubed (D^3). Therefore, short digital paths can be usually meet outage objectives with less composite fade margin (more interference) since the outage probability of fading is low.

Since the total number of seconds in one year equals 31.5×10^6, the annual path reliability is computed from:

$$Path\ Reliability\ (\%) = \left(\frac{31.5\times10^6 - T}{31.5\times10^6}\right) 100 \qquad (4.2\text{-}7)$$

The non-diversity outage equations can be rearranged to derive the analog radio Fade Margin (FM) or digital radio Composite Fade Margin (CFM) required for a given outage time:

---

7 Lee, T.C. and Lin, S.H., "A Model of Space Diversity Improvement for Microwave Radio Against Thermal Noise Outage During Multipath Fading", *IEEE Conf. Rec., 1988 Int. Conf. on Commun.*, June 1988.

$$FM \ or \ CFM \ (non-diversity) = -10 \log \left(\frac{T}{5 f D^3} \right) \quad [metric]$$

$$= -10 \log \left(\frac{T}{20 f D^3} \right) \quad [English] \qquad (4.5\text{-}8)$$

where:

T = outage time objective, sec/yr
f = frequency, GHz
D = path distance, km (mi)

Space diversity improvement plays such a significant role in increasing path reliability, it often allows higher interference levels that degrade (reduce) the composite fade margin of many digital links. By combining the non-diversity outage equation and the space diversity improvement factor equations, we arrive at the following equation for the annual outage in a space diversity path

$$T_{SD} = \frac{4 \times 10^3 \, D^4 \, 10^{-\frac{CFM}{5}}}{s^2} \quad [metric]$$

$$= \frac{3 \times 10^5 \, D^4 \, 10^{-\frac{CFM}{5}}}{s^2} \quad [English] \qquad (4.2\text{-}9)$$

Note that the frequency term has disappeared from the space diversity outage equation and the annual outage now varies as a function of D^4. Rearranging this equation to solve for the required Fade Margin or Composite Fade Margin for a given outage time with space diversity gives:

$$FM \ or \ CFM \ (space-diversity) = -5 \log \left(\frac{2.5 \times 10^{-4} \, T \, s^2}{D^4} \right) \quad [metric]$$

$$= -5 \log \left(\frac{3.5 \times 10^{-6} \, T \, s^2}{D^4} \right) \quad [English] \qquad (4.2\text{-}10)$$

Calculation of the required fade margins for non-diversity or space-diversity links with the above equations may provide improved spectrum utilization (efficiency) by permitting higher interference levels without overly degrading the required reliability for many short and diversity links. For example, if the required fade margin (above) is 25 dB, and the path calculations with no interference show 33 dB, an interference level 7 dB above the value calculated on the basis of threshold degradation (by Equation 2.5.5-1, for instance) would probably not cause the hop outage to exceed objectives.

Insert TIA Doc here!

Since analog radios are non-regenerative, the baseband noise is additive on "N" tandem hops (typically per-hop noise plus 13 log N). Fading on different hops is non-correlated, so the outage time (probability of outage) of a digital or analog radio system is equivalent to the sum of the outage times (probabilities of outage) of the individual hops. While the above outage and fade margin calculations are applicable to both analog and digital radio hops, analog radio noise buildup poses a more complex problem. With analog systems, one must consider the overall system noise objectives in parallel with the system reliability (outage) objectives. Most analog links require significant carrier level increases above threshold sensitivity just to achieve acceptable baseband signal-to-noise (e.g. >35 dB increase for 70 dB S/N in the worst message channel in an FM-FDM link).

4.3 Automatic Transmit Power Control in Digital Links

4.3.1 Introduction:

Automatic (or Adaptive) Transmit Power Control (ATPC) is a desirable feature of a digital microwave radio link that automatically adjusts transmitter output power based on path fading detected at the far-end receiver(s). ATPC allows the transmitter to operate at less than maximum power for most of the time. When fading conditions occur, transmit power will be increased as needed. ATPC is useful for extending the life of transmitter components, reducing power consumption, simplifying frequency coordination in congested areas, allowing additional up-fade protection, and (in some radios) increasing the maximum power output (improves system gain).

If the maximum transmit power in a ATPC link is needed for only a short period of time, a transmit power less than maximum may (if certain restrictions are met) be used when interference calculations are made into other systems. Many years of fading statistics have verified that fading on different physical paths is non-correlated, *i.e.* the likelihood of two paths in a given area being in a deep fade and thus sensitive to interference simultaneously is very small. Further, to allow for inevitable deep fading, microwave paths are designed with unfaded carrier-to-noise (C/N) and carrier-to-interference (C/I) ratios much greater than those required for high quality path performance. Since fading is non-correlated among paths, a short-term power increase by a path experiencing a deep fade will not reduce the C/I on other paths to an objectionable level. On a properly designed path, and one not affected by rain outage, ATPC-equipped transmitters will be at maximum power for a short period of time. However, because the maximum power is available when deep fades occur, CFM, threshold C/N, and C/I calculations into an ATPC link may assume the "Maximum Transmit Power" receive carrier level.

ATPC has been successfully implemented in FCC Part 21 common carrier bands for several years, and, under FCC *ET Docket 92-9*, is now permitted under Part 94. Currently, there are two types of ATPC available. The "ramping" type increases power dB for dB with a fade greater than a certain depth. The "stepped" type increases power in a single step to maximum power when a fade exceeds a certain depth. Besides significantly aiding the frequency coordination process, ATPC also provides receiver up-fade overload protection due to the backed-off transmit power under normal signal level conditions.

4.3.2 ATPC recommendations for frequency coordination

During the coordination process, the ATPC user must clearly state that ATPC will be used. The transmit powers associated with an ATPC system included on the coordination notice are defined as follows:

Maximum Transmit Power	That transmit power that will not be exceeded at any time, used for CFM and path reliability (outage) computations, and for calculating the C/I into an ATPC system.
Coordinated Transmit Power	That transmit power selected by the ATPC system licensee as the power to be used in calculating interference levels into victim receivers.
Nominal Transmit Power	That transmit power at or below the coordinated power at which the system will operate in normal, unfaded conditions.

where

- $D(f_r, f_t) = PSD_w * PSD_i(f_t - f_r) + PSD_w * PSD_i(f_t + f_r)$ and "*" denotes the convolution operation; $PSD_w(f)$ and $PSD_i(f)$ are the power spectral densities of the desired signal and the interfering signal, respectively, and they are assumed to be normalized to unity power and centered on the carrier frequency.

- $H(f_r) = H_{de}(f_r)$ for an FM receiver with de-emphasis filter and $H(f_r) = 1$ for an FM receiver without de-emphasis filter.

The relationship between the baseband SIR and the C/I ratio of an FM-FDM receiver involves the IRF and it is expressed as follows:[4]

$$C/I(f_r, f_t)(dB) = SIR(dB) - IRF(f_r, f_t)(dB) \qquad \text{(A-8)}$$

It is observed that when the IRF is equal to 0 dB, the C/I is equivalent to the baseband SIR; however, when the IRF is not equal to 0 dB, the C/I is equal to the baseband SIR, adjusted by the IRF. The SIR is usually predetermined based on performance considerations or sometimes mandated by regulations.

A-6 Carrier-to-Interference Objective

Add

For a given baseband signal-to-interference objective SIR_o, the carrier-to-interference objective $(C/I)_o(f_r)$ at each frequency separation f_r is defined to be the C/I ratio produced by the noisiest baseband channel corresponding to the baseband signal-to-interference objective SIR_o, that is

$$(C/I)_o(f_r) = \max_{f_{min} \le f_t \le f_{max}} \{SIR_o - IRF(f_r, f_t)\} \qquad \text{(A-9)}$$

(Unfaded FM Noise, FM Sideband or Digital Spectrum Overlap) or Intercarrier beat)

The interference reduction factor $IRF(f_r, f_t)$ is computed using Equation A-7 in Section A-5. The baseband signal-to-interference objectives SIR_o is computed as follows:

1. SIR_o (in dB) = X (in dBm0) - P (in dBm0)

   where:

   X = per-channel load (average talker power)
   P = per-hop baseband interference power objective

2. The per-channel load is regulated by *FCC Rules and Regulations* §2.203 (see Section 2.2).

3. The system baseband noise power objective is 250 pWp0 (see Section 2.5.2) and may be broken into tandem per-hop interference power objectives based on the length "L" and/or the number of hops "N" of the system.

---

[4] Equation 1, Annex 1, ITU Recommendation 766.

a. If "L" is greater than 400 km (long haul), the per-hop baseband interference power objective (in pWp0) is

$$\max\ \{5,\ 25 \times 10^{\left[1.5 \log\left(\frac{L}{400}\right)\right]}\}$$

5pw
-80.5 dBmØ

b. If "L" is less than or equal to 400 km (short haul), the per-hop baseband interference power objective (in pWp0) is

$$\max\ \{25,\ 250\ /\ n\}$$

25pw
-73.5 dBmØ

any

c. If the interfering signal is an FM-FDM signal and the baseband channel frequency f_r is equal to the frequency separation f_s (*i.e.*, the baseband channel with frequency f_r is corrupted by intercarrier beat interference), the per-hop baseband interference power objective is 50 pWp0.

ADD

-70.5 dBmØ

4. The interference power objective is converted to dBm0 from pWp0 by using the relation:

$$dBm0 = 10 \log (pWp0) - 87.5,\ \textit{flat},\ 3.1\ kHz\ \textit{bandwidth}$$

For FM systems using the same frequency plan, intercarrier beat does not happen. This interference mechanism normally only occurs when different frequency plans are used in the same geographic area.

A-7 Filter Selectivity

Note: for the purpose of frequency coordination, when the filter selectivity is not known, 0 dB shall be used.

In an FM-FDM system, the IF filter is designed so that it does not change the shape of the power spectral density of the desired signal significantly. However, the power spectral density of the interfering signal is reduced by this filter when the frequency separation between the carrier frequencies of the desired signal and the interfering signal is large (adjacent channels). The C/I objective in Equation A-9 can be re-derived to take the effect of IF filtering into account. This leads to the following equation:

$$(C/I)_0(f_s) = \max_{f_{min} \le f_r \le f_{max}} (SIR_0 - IRF(f_r, f_s) - S_e(f_r)) \tag{A-10}$$

The factor $S_e(f)$ is called the filter selectivity of the receiver and it is computed from the power spectral density $P(f)$ of the interfering signal and the transfer function $G(f)$ of the IF filter by the following equation

$$S_e(f_s) = -10 \log \left(\frac{\int P(f-f_s)\,|\,G(f)\,|^2\, df}{\int P(f-f_s)\, df} \right) \tag{A-11}$$

where the integrals are taken over the frequency interval that contains at least 99 percent of the power of the

EXHIBIT B

MSS & FS Industry Meeting Related to FCC ET Docket No. 95-18
COMSAT Corporation, Bethesda, Maryland
April 25 & 26, 1996

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